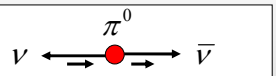
New Results on $\pi^0 \to \nu\bar{\nu}$ and Implication in Future Measurements

- Kaon2005 June 14th (Tue) 2005, Northwestern Univ.- Kentaro MIZOUCHI (Kyoto Univ.) for the E949 collaboration

Physics Motivation

$\pi^0 \to \nu\bar{\nu}$ decay



π^0 : spin 0
ν : left-handed (in the SM)

(1) Helicity suppressed decay :

(a) Finite neutrino mass indication from oscillation experiments.

(b) The decay would occur depending on the mass :

$$Br(\pi^0 \to \nu\bar{\nu}) = 6.3\times10^{-8}(m_\nu / m_{\pi^0})^2\sqrt{1-4(m_\nu / m_{\pi^0})^2}$$

(c) The current PDG limit $m_{\nu_\tau} < 18.2\,\mathrm{MeV}/c^2$ implies $Br < 1.1\times10^{-9}$

(2) Physics beyond the standard model :

(a) Decays into exotic weakly interacting neutrals
Ex. sterile neutrinos $\pi^0 \to \nu\nu'$

(b) Helicity-flipping pseudoscalar interactions

(3) Interest in Cosmology :

(a) Neutron star cooling through pion pole mechanism : $\gamma\gamma \to \pi^0 \to \nu\bar{\nu}$

The Experiment (BNL-E949)

$K^+ \to \pi^+\pi^0\,(K_{\pi2}),\ \pi^0 \to \nu\bar{\nu}$

Signature : $\pi^+(205\mathrm{MeV}/c)$+'nothing'

(1) The Experimental Method :

(a)Kπ2 identification with K+(at rest) and π+
(b)Hermetic cut to reject $\pi^0 \to \gamma\gamma, e^+e^-\gamma$

(2) Hermetic Photon Detectors : *(major parts only)*

(a)Barrel Veto, BVL : Pb + scintillator
(b)Endcap : Undoped CsI with CCD-readout

FIG 1(a) : The E949 detector Side view (upper half)

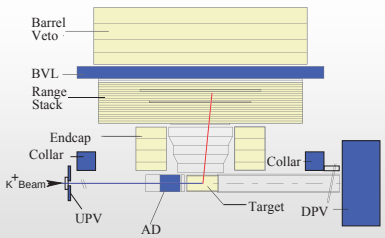
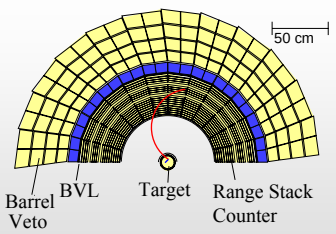


FIG 1(b) : End view (upper half)



Color index : Photon detectors from E787 (Yellow), new/updated parts in E949 (Blue)

Analysis

FIG 2 : Analysis flow

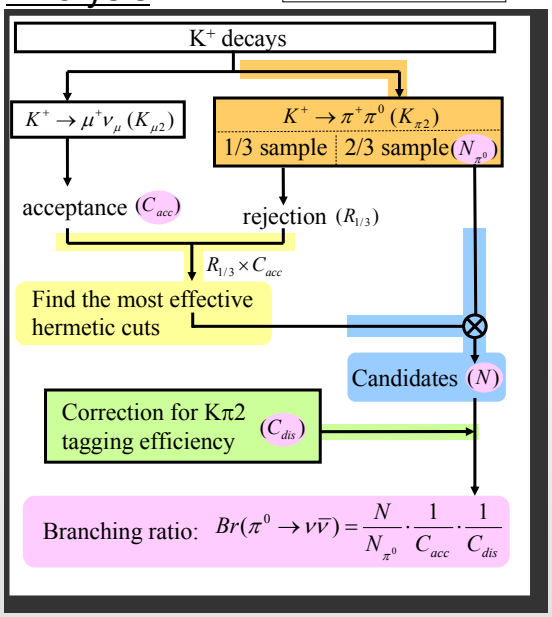


TABLE 1: Number of backgrounds in the tagged Kπ2

Total non-$K_{\pi2}$ background	$3.12^{+1.98}_{-0.99}$
• $K_{\mu2}(\gamma)$ background	$0.367^{+0.069}_{-0.060}$
• π^+ beam background	$0.0327^{+0.0013}_{-0.0099}$
• Two beam background	$2.72^{+1.26}_{-0.92}$
Number of stopped K^+ (N_K)	1.8×10^{12}
Number of tagged π^0 (N_{π^0})	3.02×10^9
Number of $\pi^0 \to \nu\bar{\nu}$ candidates (N)	99

(1) High Purity Kπ2 Identification :

(a) Precise π+ kinematics measurements (E/P/R)
(b) [Kμ2 rejection] Trace pion decay sequence
(c) [π+ beam rejection] Wait at least 2ns after the K+ comes to rest in target.
(d) [two-beam rejection] Beam line veto around the K decay time.
(e) ***Impurity ~10^{-9}. The number of π^0*** $N_{\pi^0} = 3.02\times10^9$ ***(See TABLE 1).***

(2) Hermetic photon cut optimization :

(a) Maximize the single event sensitivity
(b) Simultaneous acceptance and rejection measurement
(c) ***Finalize the cut parameters***
Timing windows and energy thresholds for more than 20 sub-detectors.
(d) ***The final acceptance :*** $C_{acc} = 0.117$

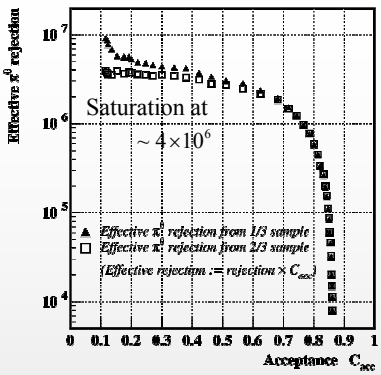
(3) Opening the signal box :

(a) A total of 99 candidates found.
(b) Poisson statistics limits signal < 113 at 90% CL.

(4) Correction factor for Kπ2 tag eff :

(a) π+ kinematics flawed by overlapping γ, e+- from π0.
(b) [MC] Normal Kπ2 decay vs. Kπ2 with $\pi^0 \to \nu\bar{\nu}$
(c) The difference : $C_{dis} = 1.14$

FIG 3: Eff π^0 Rejection vs C_{acc}



Effective rejection (which is defined as "π^0 rej"×C_{acc}) as a function of C_{acc}

(5) The result :

(a) Suppose all were signals.
(hard to estimate $\pi^0 \to \gamma\gamma$ bkgnd.)

$N_{90} = 110\ (\sim 113 - 3.12)$

$$Br(\pi^0 \to \nu\bar{\nu}) < \frac{110}{3.02\times10^9}\cdot\frac{1}{1.14\times0.117} = 2.7\times10^{-7}$$ ***New upper limit !***

The previous limit :
$Br(\pi^0 \to \nu\bar{\nu}) < 8.3\times10^{-7}$(BNL-E787, 1991)

Results

The $\pi^0 \to \nu\bar{\nu}$ search was performed with a sample of π0 ($N_{\pi^0} = 3.02\times10^9$) tagged with Kπ2 decay. An upper limit of $Br(\pi^0 \to \nu\bar{\nu}) < 2.7\times10^{-7}$ was obtained, a factor three improvement over the previous limit.

Future: Photon Detection Inefficiency

For future experiments, "single photon inefficiency"(SPI) of the hermetic detector was measured with real data ("one photon mis-detected Kπ2"), and checked if the measured inefficiency was consistent with the number of candidates observed.

The statistics on the SPI measurement didn't reach to the required level, but at looser cut, π0 rejection (FIG 5) was reproduced. This study hinted a possibility of further improvement of the $\pi^0 \to \nu\bar{\nu}$ search through the $\pi^0 \to \gamma\gamma$ background subtraction.

FIG 4: photon inefficiency

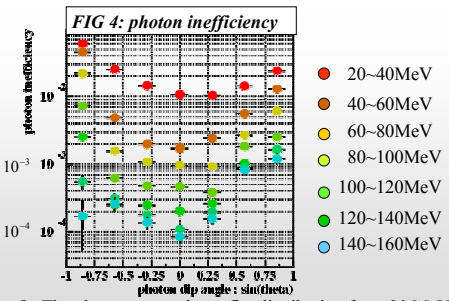
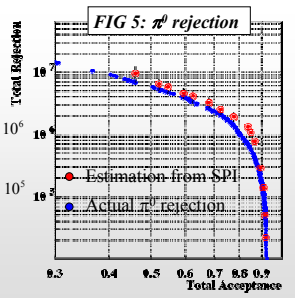


FIG 5: π^0 rejection



[Note on $\pi^0 \to \gamma\gamma$] The photon energy has a flat distribution from 20 MeV to 225 MeV, and the total sum is 245MeV.